System Level Simulations for Cellular Networks Using MATLAB

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Cellular Networks

- Cellular Network: A wireless communication network that ideally provides ubiquitous voice & data service
- Deployment:
  - Base stations (BS) of varied transmit power levels are installed on a terrain
  - Receivers of users (UE) decode signals from “attached” Base Stations
- Challenge: Terrain and propagation effects significantly affect performance
- Solution: Schemes that mitigate challenge have to be evaluated using Link & System Level Simulations before deployment

Fig. courtesy of: 4GAmericas
System Level Simulation Process

- **Deployment**
  - System configuration

- **Move UE’s: Pre-Defined Mobility Pattern**

- **Link Establishment**
  - (BS-UE Association)

- **Scheduler**
  - (PF / RR)

- **Channel Generation**
  - (LoS/NLoS Channel)

- **Receive Processing Feedback Report**

- **Measurement & Processing Handover Execution**

- **Metrics**
  - (Throughput & Handover)

**Basic modules**

**Throughput Modules**

**Mobility Modules**
Deployment: BS & UE Placement

- Place BS at the center of a hexagon
- Randomly drop UE’s in rectangular area
- Discard UE’s dropped in the discard region
• Find Nearest Cell to a UE using wrap around model
• Wrap around model ensures correct mapping of distance from UE to all Base Stations
Find the set of neighboring 19 cells for each UE according to the wrap around model.
Calculate path loss and shadow from neighboring 19 cells 3 sector
Find serving cell and sector: Lowest path loss including shadow effect
• Identify interferers from 19 cells
Design of Parameters for Deployment

BS & Pico Deployment
- Inter BS/Pico Distance and Number of Picos/Sector, UE’s/Sector
- Transmit Power Levels and Antenna patterns

Fading
- Large Scale Fading: Line of Sight (LOS), Non-Line of Sight (NLOS)
- Shadow Fading
- Small Scale Fading Models

Coverage Maps
- SINR Profile
- Throughput Profile

Mobility
- Handover Parameters
- UE Mobility Pattern

Data Traffic
- Full Buffer
- Partial Buffer: Arrival Rates

Resource Allocation
- Choice of Scheduler Algorithm and Granularity of Allocation
- Transmission Modes: Single, Multiple, Coordinated Transmission

Metrics
- Throughput
- Mobility

- Iterative
- Time Consuming
Design of Parameters Using Symbolic Math Toolbox

Fig. Deployment of Base Stations and Users according to a Poisson Point Process Model (PPP)

PPP model accurately models the large scale SINR for several practical deployment scenarios

Fig. Deployment of Base Stations by a major cellular network provider in 40 X 40 Km area.

Integral of Hypergeometric Function Evaluated Using Symbolic Math Toolbox

Obtain Density of BS for required Throughput

Ergodic Rate as given in, “Modeling, Analysis and Design for Carrier Aggregation in Heterogeneous Cellular Networks,” X. Lin, J.G. Andrews and A. Ghosh
## Design of Deployment Parameters Using Symbolic Math Toolbox

### BS & Pico Deployment
- Inter BS/Pico Distance and Number of Picos/Sector, UE’s/Sector
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### Fading
- Large Scale Fading: Line of Sight (LOS), Non-Line of Sight (NLOS)
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### Mobility
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### Metrics
- Throughput
- Mobility

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Parameters Designed Using PPP Model and Symbolic Math Toolbox

- Fewer Iterations
Scheduler

- Preliminaries:
  - Each time-frequency resource is called Resource Element (RE)
  - A group of RE’s form an Allocation Unit (AU)
  - Each spatial layer has N AU’s

- Assumptions:
  - K Users in set U={U_1, U_2, ...U_K}
  - L possible Transmission Modes (one at a time)

- Role of Scheduler:
  - Allocate M*N resources among K Users in time-frequency
  - Let w be a metric that indicates the weight considering proportional fairness criterion, say
  - Then, the resource allocation is according to:

\[
\hat{x}(i, j, \hat{a}, \hat{l}) = \arg \max \sum_{a=1}^{N} \sum_{l=1}^{L} \sum_{i \in U} \sum_{j \in U} w_{i,j}^{a,l} x_{i,j}^{a,l}
\]

s.t.  \[
\sum_{a=1}^{N} \sum_{l=1}^{L} x_{i,j}^{a,l} \leq NL, \quad i, j = 1, 2, \cdots, K
\]

\[
x_{\text{opt}}(\hat{i}, \hat{j}, \hat{a}, \hat{l}) = 1
\]

\[
w_{i,j}^{a,l} = \log \left(1 + \frac{r_{j,k}^{a,l}}{(T-1)\bar{R}_{j,k}}\right)
\]

\[
r_{j,k} - \text{Instantaneous rate to MS j and k}
\]

\[
\bar{R}_{j,k} - \text{Average rate to MS j and MS k over time window } T
\]
Scheduler: Numerical Solution Using MATLAB

- Use MATLAB’s Compiler Runtime Engine
- Solve using MATLAB’s Optimization Toolbox:

\[
(i, j, a, l) = \arg \max \sum_{a=1}^{N} \sum_{l=1}^{L} \sum_{i \in U} \sum_{j \in U} w_{i,j} x_{i,j}^{a,l}
\]

\[
s.t. \sum_{a=1}^{U} \sum_{l=1}^{L} x_{i,j}^{a,l} \leq NL, \quad i, j = 1, 2, \ldots, K
\]

\[
x_{opt}(i, j, a, l) = 1
\]

- Use Binary Integer Programming to Solve the problem
- Link the script for optimization to C++ SLS using dynamic linked libraries
- Harnesses the power of MATLAB’s Optimization Toolbox
- Save implementation time for developing complex optimization routines
Scheduler: Numerical Solution Using MATLAB

- MATLAB’s Optimization & Global Optimization Toolbox:
  - Wide array of solvers helps to choose different optimization techniques
  - CVX Toolbox increases options to solve the problems
    - Ease of representation
  - Certain scheduling algorithms have multiple local minima
    - Solution: Use functions from Global Optimization Toolbox

- Advantages:
  - Evaluation of System performance:
    - Optimal Algorithm with MATLAB Toolboxes provides limits of performance
    - No artificial limit on performance due to sub-optimal algorithms
    - Give insights to standards on limits of performance, paving way for improved system design
  - 50% decrease in simulation time
Summary

• Faster Turn-Around Time Using Symbolic Math Toolbox for design of deployment and mobility parameters

• Harness numerical optimization package of MATLAB to solve complex scheduler optimization and interface it to C++ based SLS using Matlab Compiler Runtime